Fiber Reinforced Composite Pipelines

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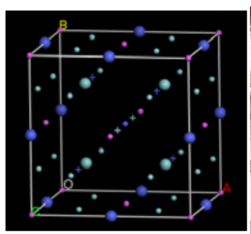
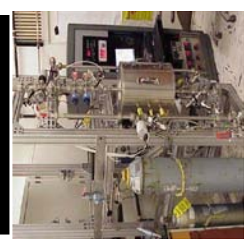
April 2010





Project ID #: PD022

Overview

Timeline

- Project start date:10/06
- Project end date:10/10
- Percent complete:60%

Budget

- Funding for FY09
  - FRP Pipeline: $300K
- Funding for FY10
  - FRP Pipeline $175K

Barriers

- Barriers Addressed
  - Hydrogen Leakage: <0.5%
  - $490K/mile and $190K/mile Transmission and Distribution Costs
  - Safe delivery of hydrogen of hydrogen at a cost target of $1.00/gge

Partners

- Commercial FRP Manufacturers
- ASME

Relevance – 2010 DOE Technical Targets

"Develop hydrogen fuel delivery technologies that enable the introduction and long long-term viability of hydrogen as an energy carrier for transportation and stationary power"

-DOE Hydrogen Delivery Goal

Target	Units	2012
Pipeline : Transmission	$/mile	$600,000
Pipeline : Distribution	$/mile	$270,000
Reliability/Integrity		Acceptable for H_2 as Energy Carrier (2017)
H_2 Leakage		<0.5% (2017)

Hydrogen Pipeline Delivery Targets

Objectives

- Overall Project Scope:
- Focused evaluation of fiber reinforced composite piping for hydrogen service applications.
- Assessment of the structural integrity of the FRP piping and development of a life management methodology

- Challenges:
- Reduced Installation Costs for FRP is an Attractive Attribute—One that Offers the Potential to Meet the Long Range (2017) Cost Targets for Installed Hydrogen Delivery Pipeline—Critical Issues That Need to be Addressed are as Follows: FRP Liner Hydrogen Embrittlement Susceptibility, FRP Liner Hydrogen Permeation, Qualification of Joint/Joint Components, and External Damage Robustness

- Development of a suite of standardized test for assessment of hydrogen compatibility of FRP

- Development of a Structural Integrity/Life Management Methodology Similar to B31.8S

- Post FY09 AMR Project Scope
- Complete leak testing of commercial FRP joining technologies
- Initiate Life Management Methodology Development

Fiber Reinforced Composite Pipeline Design Specification

- ASME B31.12 Does not address non-metallic piping

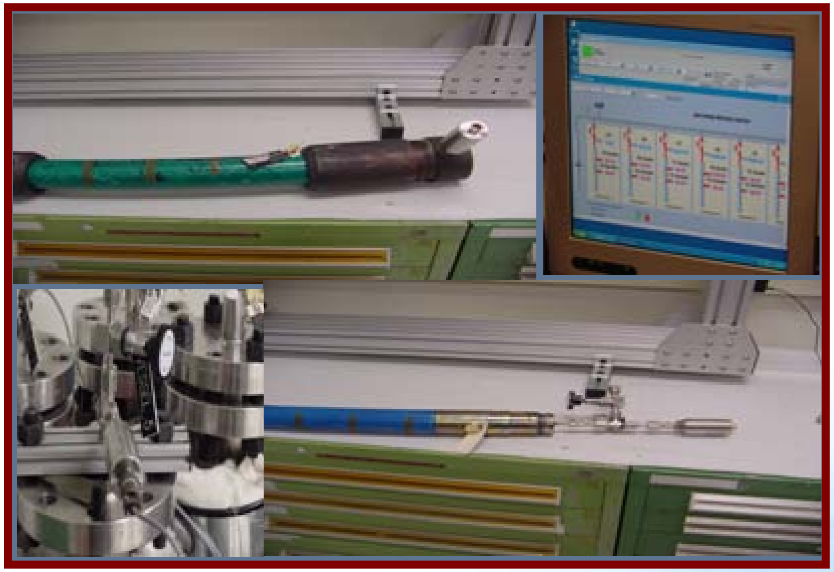
- Technical basis is needed to provide direction to Users, Designers, and Manufactures to facilitate the application of FRP and non-metallic piping

- Performance based approach is proposed to address needed testing and acceptable criteria

  - Design Pressure
  - External Loads
  - Permeation/Leakage

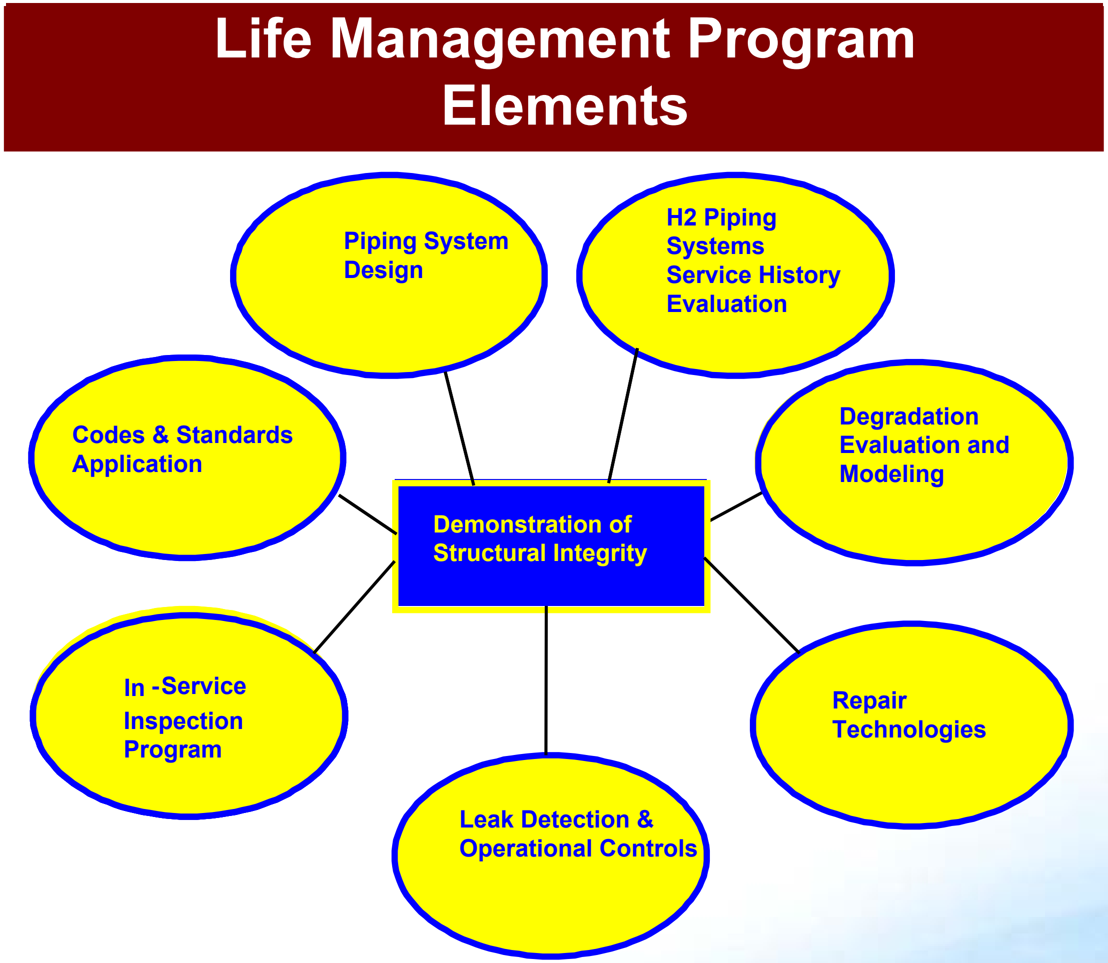
- Hydrogen Specific Testing Techniques for Design Quality Data??

- **DOT Gap Analysis Report Identifies 4 Major Needs for Composite FRP Piping**
  - ***Lack of Design Specifications***
  - **Qualified Joints/Joining**
  - **Permeation**
  - **Robustness to External Damage**



Development of FRP Life Management

- A white paper prepared by SRNL and ASME has been developed that outlines the necessary elements for Design and Life Management for FRP for Hydrogen Service
- The execution of the plan will provide the needed technical basis to complete a:
  - FRP Design Section in B31.12
  - Structural Integrity standard for FRP (B31.8S)
- This technical basis is required to proceed with the ASME Code development of FRP for Hydrogen Service
- The work will be proposed as a joint industry and government project
  - Plan to discuss funding with DOE, DOT, FRP Manufacturers, Industrial Gas Suppliers, and Industrial Pipeline Constructors



Development of FRP Life Management

- SRNL in collaboration with ASME has developed an FRP Life Management Plan

- Detail investigation is needed in the following areas:
    - System Design and Applicable Codes and Standards
    - Service Degradation of FRP
    - Flaw Tolerance and Flaw Detection
    - Integrity Management Plan
    - Leak Detection and Operational Controls Evaluation
    - Repair Evaluation

Fiber Reinforced Composite Pipeline Design Specification

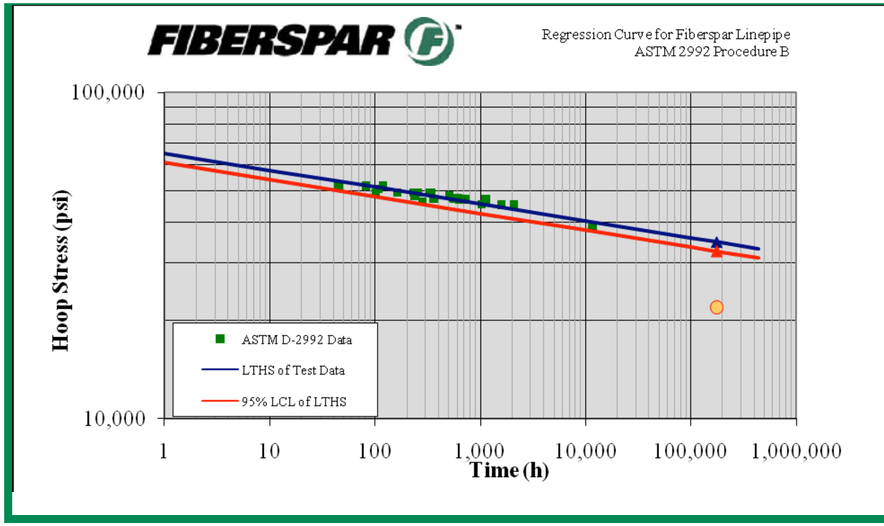
- Standards Reviewed
  - API 15HR, Specification for High Pressure Fiberglass Line Pipe
  - AWWA C950 Fiberglass Pressure Pipe
  - ASME Code Case N-155-2 Fiberglass Reinforced Thermosetting Resin Pipe
  - ASME B31.3 Process Piping
  - ASME B31.8 Gas Transmission and Distribution Piping
  - ISO 14692 Petroleum and Natural Gas Industries Glass-reinforced plastics (GRP) piping
- These documents used the ASTM D2992 (Hydrostatic Design Basis) to establish an allowable design margin to address creep rupture. A performance based standard may need to address all the technical issues for hydrogen pipelines

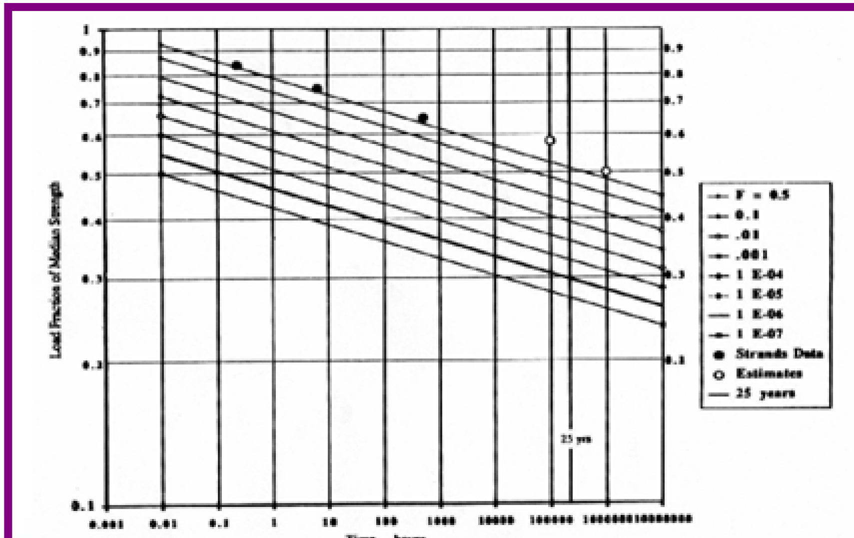
Design Margin for FRP

- Stress ratios are being set in many newer standards to address reliability in regards to stress rupture as compared with the Hydrostatic Design Basis used in ASTM D2992.

- The date provided by Robinson, Aerospace Corporation has shows that a margin of 3.5 on the burst pressure (.28 Stress Ratio) will provide a creep rupture life of 25 years

- Burst data for FRP Design to ASTM D2292 indicated that the margin on burst of 4.0. indicating that there is additional margin to address factors like third party damage, environment and additional service.





Robinson Aerospace Corporation

Service Degradation of FRP

- The design margin must address the environmental effects for the local conditions
- The relevant data from the composite pressure vessel industry (NGV) shows that the highest percentage for failure is from chemical attack.
- The API 15HR Specification for High Pressure Fiberglass Line Pipe indicated the need to address an environmental service factor. But does not provide a methodology.
- Corrosion resistant glasses need to be considered
- A performance test as applied in pressure vessel standards may be a better option.

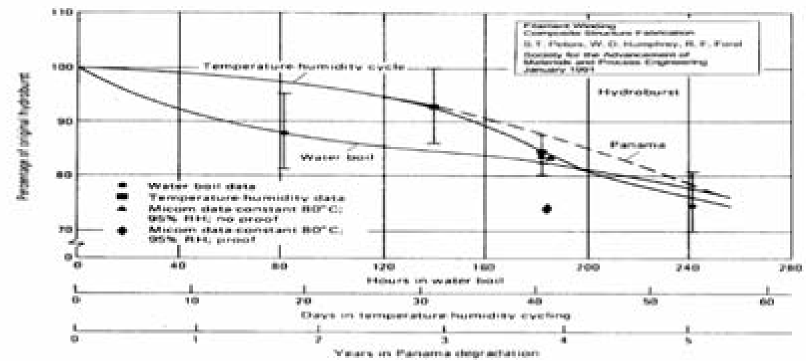
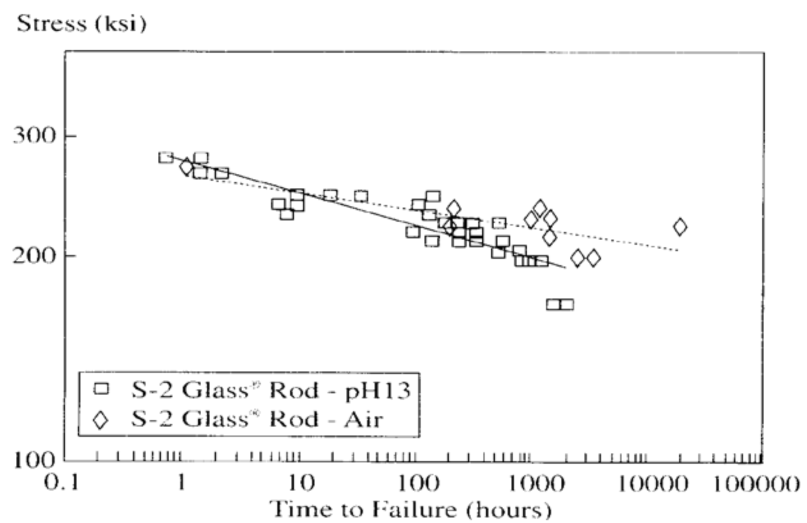


Figure 8-5. S-Glass/Epoxy Degradation Rates.



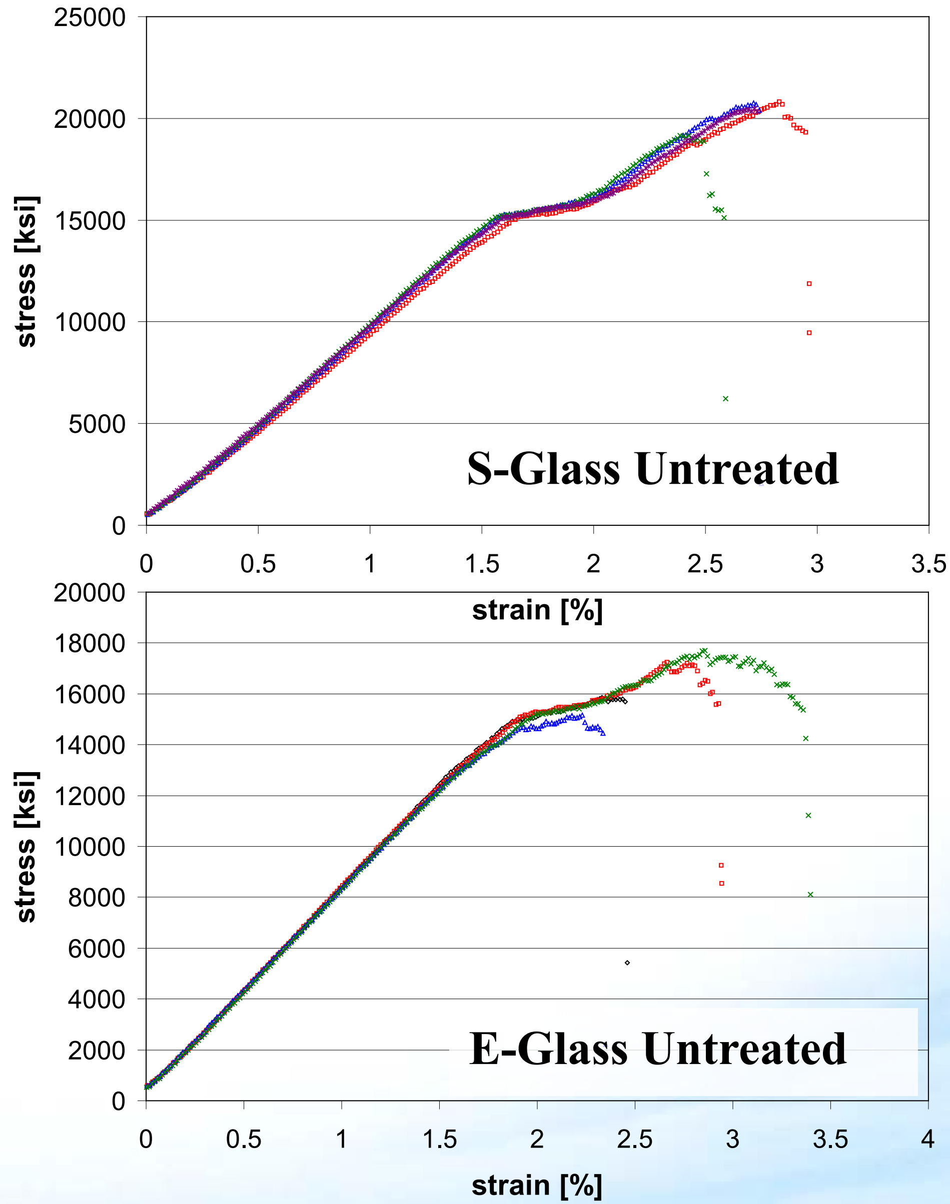
AGY Technical Literature

Fiberglass Chemical Exposure Testing Procedure

- pH controlled by using nitric acid and sodium hydroxide
  - 2.4, 7, and 11.6 as initial values to hit major environmental extremes
- Room temperature was employed for testing as more representative of ground installations (20 ^{o}C / 68 ^{o}F)
- S and E glass yarns of nominal diameter 10 μm exposed for 24 hr and 120 hr durations
- Tensile Strength measured using an Instron 4507 with a 200 lb load cell and slow strain rate of 200 μm/sec per ASTM 1557-03
- Chemical resistance measured by monitoring mass loss after exposure

Typical Tensile Strength Results

- Values are typically higher than those previously reported
  - Much slower strain rates used allow higher stresses to be achieved
  - 200 µm/sec vs 12 in/min* (~800 µm/sec)
- Experiments show very good reproducibility within data sets



*Hartman, D; Greenwood, M.; and Miller, M. "High Strength Glass Fibers" *AGY Technical Paper*. (2006)

Chemical Exposure Tensile Strength Results

Untreated Samples		
	S-Glass	E-Glass
Tensile Strength [ksi]	19,971	16,485

S-Glass Threads Tensile Strength [ksi]		
pH\t_exp [hr]	24	120
2.4	14,325	7,611
7	19,629	19,941
11.6	15,667	17,552

Typical failure showing rupture with test specifications, not at grips

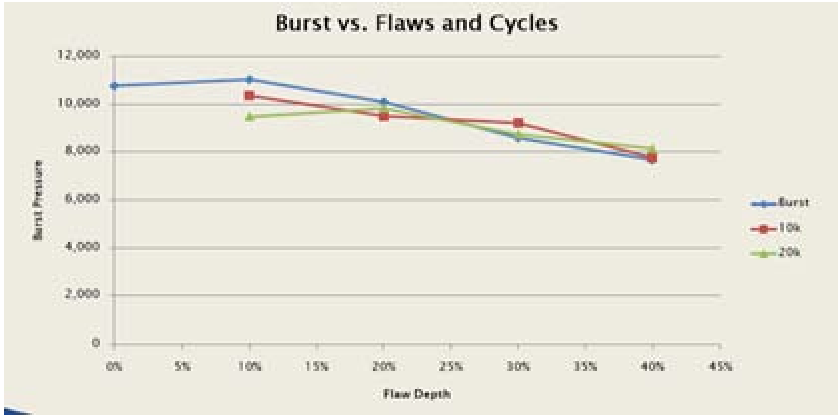
E-Glass Threads Tensile Strength [ksi]		
pH\t_exp [hr]	24	120
2.4	13,432	10,528
7	9,227	14,270
11.6	12,831	9,928

Flaw Tolerance

- To address the third party damage issue the sensitivity of FRP to flaw must be established

- A testing program to evaluate flaw tolerance in pressure vessels has recently been completed by Lincoln Composites, ASME and DOE showing providing positive results

- SRNL is in the process on preparing samples to start flaw evaluation for FRP. The tests will be coordinated with internal examination to evaluate flaw detection techniques



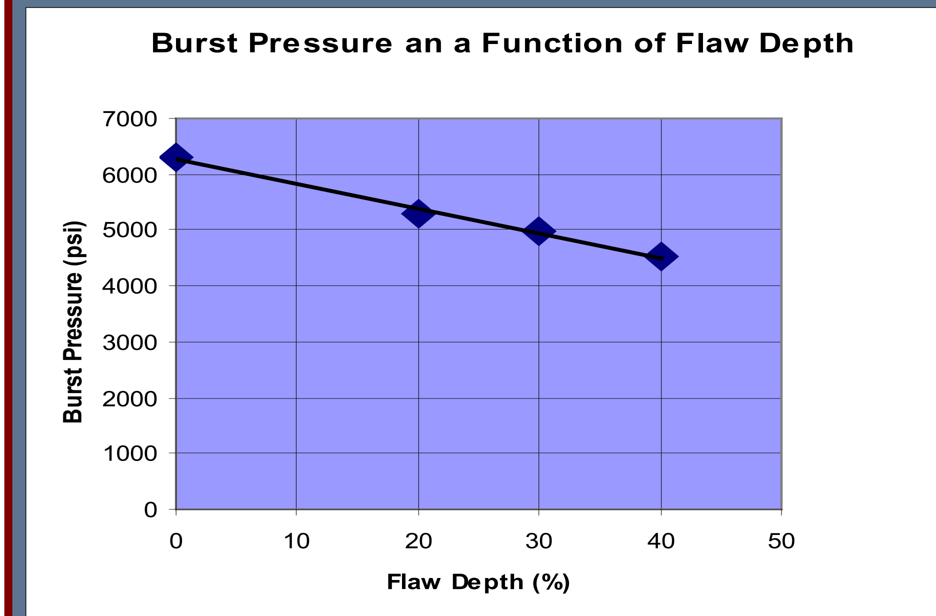
Proposed Flaw Testing Matrix		
Test	Longitudinal Flaw Depth	Circumferential Flaw Depth
1	**20**	-
2	-	**20**
3	**30**	-
4	-	**30**
5	**40**	-
6	-	**40**

Fiber Reinforced Composite Pipeline

Evaluation of Third Party Damage

Multi - Layer Reinforcement

- Reduction in Burst Pressure from unflawed condition to 40% through wall flaw of 28 % for short term burst and multiply layer reinforcement
- With the 40 % through wall flaw there is still a margin of 3 above the rated pressure
- Larger flaws and creep effects still need to be reviewed.



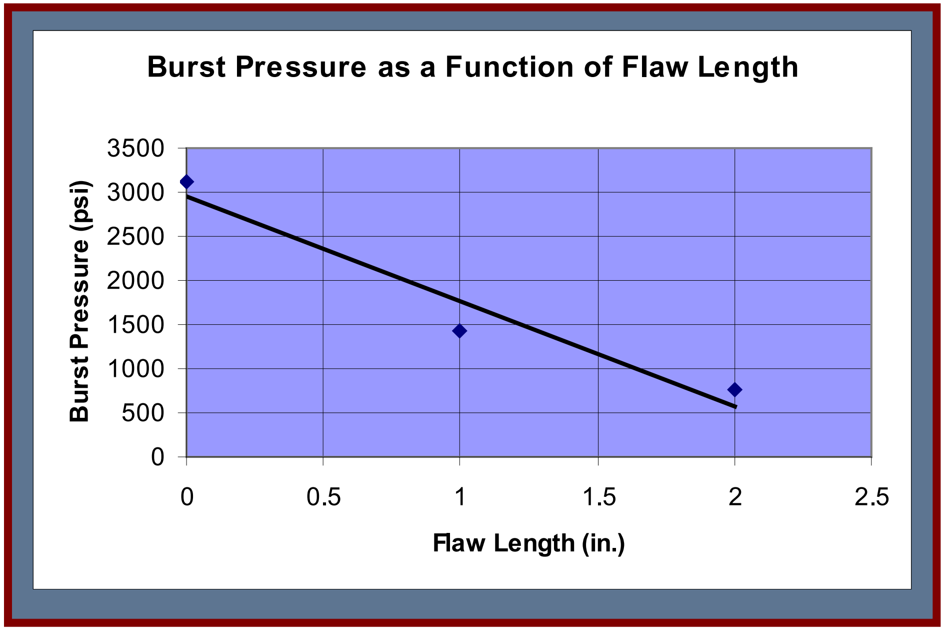
Failure mode changes from global to local and then move back towards global as flaw depth increases

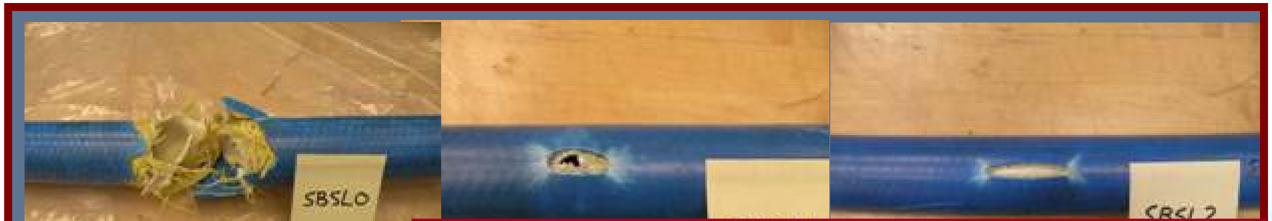
Fiber Reinforced Composite Pipeline

Evaluation of Third Party Damage

Single Layer Reinforcement

- Reduction in burst pressure from unflawed condition to a 2 inch long flaw cutting the reinforcing layer of 75 % for short term burst and multiply layer reinforcement
- With the 2 inch long flaw cutting the reinforcing layer the burst pressure drops below the rated pressure
- The single layer reinforced piping does not provide sufficient redundancy to tolerate third party damage





No Flaw resulting in global failure

1 and 2 inch flaws through the reinforcing layer resulting in local failures

Summary

- FRP Pipe Fabricated API 15HR is the most relevant Standard reviewed to date for the fabrication of FRP line pipe for hydrogen service. This standard can be tailor to address the need for hydrogen pipelines

- Scoping tests show that the burst pressure obtained using the ASTM D2992 (Hydrostatic Design Basis) provides additional design margin above what is needed for stress rupture when compared to the Lawrence Livermore long term tests

- The initial environmental test indicate that a service factor for will need to be evaluated for all installations. Acceptable performance tests need to be developed to address the environmental effects and flaw tolerance.

- The current recommendation is to develop a performance based design specification to be included in ASME B31.12
- An ASME review is planed for the work in August